CICE Consortium

Progress Report

February 2022 - June 2023

Overview

The CICE Consortium accomplished a number of major upgrades to our sea ice model code, scripts and testing infrastructure, while strengthening our visibility in the international modeling community. We released CICE versions 6.4.0, and 6.4.1, each of which include updated releases of Icepack (versions 1.3.2, 1.3.3). The major new capability in the last year was addition of C-grid infrastructure and support of the EVP solver on a C-grid. Improvements were also made to the delta-Eddington radiation scheme, to the advanced snow physics, to the floe size distribution, to the VP dynamics solver, to salinity coupling options, and to the interface between Icepack and driver codes (including CICE).

A list of member institutions, their representatives, and their contributions to the Consortium is provided later in this document. Ruth Preller retired from the Naval Research Laboratory in 2022, leaving a gap in the Executive Oversight Board (EOB), both as NRL representative and EOB Chair, which has not been filled. Riick Allard has been filling in as NRL's EOB member. Jean-Francois Lamarque also left his position as CGD Director at NCAR; Marika Holland has been filling in as NSF/NCAR EOB member.

Major initiatives and institutional milestones

The Consortium's primary goal is to accelerate model development for sea ice research and the adoption of those developments into operational codes at forecasting centers. Successes this year include

- DOE began merging Icepack into E3SM, leading to several bug fixes and other improvements to the code.
- NRL has incorporated CICE6 into the Navy Earth System Prediction Capability V2 deterministic system, which is scheduled for operational implementation by the end of 2023. The inclusion of landfast ice from CICE6 would not be possible without the contributions from the CICE Consortium. Validation testing of the ESPC V2 ensemble-based system with CICE6 is underway.
- NCAR has incorporated CICE6 into CESM. Incorporating CICE6 allows NCAR to take advantage of other Consortium developments including the improved snow physics, landfast sea ice, C-grid, floe size distribution and wave interaction, and eventually the biogeochemistry.
- ECCC is leading the C-grid effort needed by multiple institutions, while moving their systems to CICE6. ECCC's operational deterministic systems (GIOPS, GDPS, RIOPS, CIOPS) and ensemble prediction systems (GEPS, CANSIPS) will soon incorporate CICE6. ECCC will also replace the CCSM3 shortwave radiation scheme with the delta-Eddington radiation scheme along with the latest improvements included in CICE6.
- DMI has incorporated CICE6 at higher resolution in order to provide a better forecast for the ice service. Close collaboration with the CICE consortium has allowed for easier integration of new versions, e.g. of the 1D EVP solver, which is likely to be moved into the operational setup as part of the next update of the DMI operational model. In addition, the coupling between NEMO and CICE has been upgraded to the newest version of both model codes based on existing versions of CICE 5 and NEMO 3.
- IOPAN continues to support CICE6 in the Regional Arctic System Model

- NOAA has integrated and validated CICE6 in the Unified Forecasting System
- Through tutorial materials in development by NASA's and NCAR's team members, the Consortium is pursuing new avenues for reaching out to early career scientists. CICE and Icepack also provide a framework for model-data comparisons using NASA's observational data sets, a capability currently under development.

Other institutions are adopting and using CICE and Icepack:

- CICE or Icepack were mentioned in all of the proposals to a recent Arctic & Climate call from the EU Commission, an indication of the influence this effort continues to have in the community.
- CICE is being tested in several of NOAA's Operational Forecast Systems, including GLOFS (Great Lakes), ALCOFS (Alaska Coastal), and RTOFS (Real-Time Ocean Forecast System). NOAA's UFS uses CICE as a separate sea ice model component, and they are instituting a formal requirement that CICE be used in all of their coupled modeling systems, for consistency.
- The Arctic Marine Forecasting System of Europe is using CICE (ARCMFC).
- An NSF-funded project is improving Icepack using data from MOSAiC.
- GFDL continues to incorporate parts of Icepack into its integrated ocean-ice model, while also working with NCAR to integrate their MOM6 ocean model into CESM, coupled with CICE6.
- Several modeling centers that use CICE, including Navy/NRL and ECCC, have been contributing simulation data to the SIDFEx (Sea Ice Drift Forecast) Experiment for the Arctic. The Endurance22 project requested input from them for the Antarctic, to help guide their successful search for the Endurance wreck.
- Snow researchers at the Finnish Meteorological Institute are interested in proposing a machine-learning-assisted physics option for the delta-Eddington radiation lookup table, based on Liston's very detailed snow model.
- The Bluelink consortium includes various Australian modeling centers, universities, and their Bureau of Meteorology (BoM). ACCESS-NRI is a new organization ("National Research Infrastructure") being set up in Australia to support development and research with the Australian Community Climate and Earth System Simulator (ACCESS) modeling system framework. ACCESS-NRI works closely with the Australian Bureau of Meteorology (BoM) and the COSIMA collection of universities and other groups using and developing the model. ACCESS-NRI would like to join the CICE Consortium, once they have staff in place. BoM currently plans to move to NEMO/SI3 eventually, and the Australian groups will need to work out among themselves how to support either or both modeling systems.
- Some promising job ads:
    - The Canadian Climate Center (CCCMA) is looking to hire someone with CICE experience to couple CICE with NEMO.
    - A University of Maryland professor is looking for a postdoc to work on data assimilation for CICE, in collaboration with NOAA EMC and GFDL.
    - A U. Washington Ph.D. student is working on data assimilation for Icepack using DART.

In addition to the major code additions and improvements listed below, the Consortium continued its intensive C-grid collaboration and embarked on a new one, working with DOE developers to merge Icepack into E3SM. Along with thorough testing and improvements to the Icepack interface, these efforts have led to a number of bug fixes and are a prime example of multiple institutions working together to accelerate model development and its transfer into operational use.

Major improvements for Icepack since February 2022 include

- Expanded salinity coupling options
- Provided internal data for the advanced snow physics and the delta Eddington radiation scheme

- Added a 5-band option to the delta Eddington radiation scheme
- Added NetCDF restart output
- Deprecated several code modules

CICE model development highlights include

- Implemented an EVP solver on the C-grid
- Modified the remapping transport scheme for use with the C-grid
- Incorporated C-grid and wave-ice coupling in coupled model caps
- Updated the VP solver to improve robustness and performance
- Refactored EVP for improved performance and flexibility
- Deprecated several code modules
- Expanded idealized testing options.

Software engineering upgrades include

- Updated and expanded grid infrastructure to support C and CD grid developments
- Refactored optional argument implementation in Icepack public interfaces to improve robustness
- Refactored the global sum infrastructure to improve performance
- Updated the global sum unit test and added a haloUpdate unit test
- Improved history and diagnostic output
- Refactored idealized box tests and added modal aerosol tests to the CICE and Icepack test suites.

Home page	https://github.com/CICE-Consortium
Zenodo Community	https://zenodo.org/communities/cice-consortium
Resource Index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
Forum	https://bb.cgd.ucar.edu/cesm/forums/cice-consortium.146/
CICE repository	https://github.com/CICE-Consortium/CICE
CICE releases with lists of enhancements and bug fixes	https://github.com/CICE-Consortium/CICE/releases
Icepack repository	https://github.com/CICE-Consortium/Icepack
Icepack releases	https://github.com/CICE-Consortium/Icepack/releases
Trunk from subversion repository	https://github.com/CICE-Consortium/CICE-svn-trunk
Archived subversion repository (private, requires permission)	https://github.com/E3SM-Climate/CICE-archive

Work Plan Updates

The following text updates the status of each of the items we called out in our 2022 Work Plan.

Tasks completed

Optimize VP performance
Several upgrades were made to improve overall performance of the viscous-plast (VP) dynamics solver. The global sum performance was also evaluated in VP, and while improvements were made to the general infrastructure, a custom, high-performance global sum is now available in VP for production use. Some other changes also sped up the solver, which were found somewhat fortuitously as part of this effort.

Updates to JRA55 forcing data
The JRA55 forcing data currently used for our testing is based on the raw JRA data. JRA55-do was developed by other groups specifically for ice-ocean modeling, with improvements targeting the high latitudes, and has now been added to our tests and forcing data offerings.

Institute unit tests where it makes sense
Unit tests have been added as needed to either test code that is not normally covered or to validate particular methods, checking outputs generated by the subroutines based on well defined inputs. The unit tests are part of our test suite, and each unit test has its own top level driver, written in Fortran, that defines input data, calls CICE methods, and checks the results. These tests both validate the methods and cover methods that may not yet be used in CICE. New unit tests include

- halochk - checks the haloUpdate infrastructure for all interfaces (2D, 3D, 4D, real, double, integer, logical), field types (scalar, vector, angle), and field locations (center, NE corner, N face, E face). Test suite includes tests for all supported grid types including rectangular, displaced pole, tripole, and tripoleT.
- sumchk - checks the CICE global sum infrastructure. Expanded the unit test to include tripoleT tests.

Code deprecation
To reduce code complexity and encourage use of better physical parameterizations, we continue to use the deprecation process defined last year. Deprecated code will remain available in our repositories, and deprecated data will continue to be accessible from our zenodo community site.

This year, the 0-layer thermodynamics, CESM melt ponds, and zsalinity options and some older forcing options were formally deprecated. The original ridging participation and distribution functions and the CCSM shortwave scheme were also considered for deprecation but were kept. NOAA colleagues reported that the old ridging participation and distribution functions are sometimes stable in SIS when the new functions are not. Both ECCC and NRL currently use the CCSM shortwave scheme, so we did not deprecate it. The deprecation process helps us determine how the community is actually using the code.

CICE and Icepack physics bug fixes and software upgrades
As usual, fixing bugs is an ongoing process, particularly as newer features are exercised in more configurations by the user community. In addition, unit testing helps uncover bugs in infrastructure for cases not generally used. For example, bugs were fixed in the global sum and halo update infrastructure as unit tests were implemented and expanded to improve testing coverage. Several bugs were fixed in the new floe size distribution and advanced snow physics options, the delta Eddington radiation code,

probabilistic seabed stress, VP solver, and for ridging in Icepack standalone configurations. Some diagnostics bugs were also fixed.

Completed Pull Requests
From February 2022 through June 2023, the Consortium team submitted, reviewed and merged 102 Pull Requests (PRs) into the CICE and Icepack repositories. 75 PRs were merged for CICE and 27 for Icepack. Many additions and corrections were also made to the About-Us repository and all of the wikis.

Continuing or ongoing tasks

Implement C-grid option
Most of the Consortium's member institutions (NOAA, ECCC, DMI, NCAR, NRL) are now using or moving toward C-grid ocean models, for which a compatible sea ice model is desirable for more effective ice-ocean coupling. A working group established to address Consortium members' needs for a C-grid option made excellent progress last year through a series of "coding camps". The resulting code was merged into the main CICE repository and released for further testing and tuning in coupled modeling systems. The release was done in two stages, first with C-grid changes that did not affect B-grid results (i.e. they were bit-for-bit), then a later release with non-bit-for-bit modifications. A CD-grid version was started but has been disabled in the main branch until it is more thoroughly tested and debugged. We decided to keep C-grid code co-located with B-grid code, which required a name change in the CICE code directory structure. The suite of idealized "box" tests was greatly expanded as part of the C-grid implementation, including a new, variable-resolution box test.

Incremental remapping advection also needed to be implemented for the C-grid, to enable advection through very narrow straits. Tests using upwind advection on native C-grid locations produced much more similar B- and C-grid simulations than incremental remapping. A C-grid checkerboard instability was discovered in idealized test cases with corners, associated with an interaction of the new momentum / stress solver with the incremental remapping advection scheme. A solution was already available in the advection code, as an option, which uses the cell-edge velocities to adjust the area being advected across the cell edge. However, this option had not been thoroughly tested and is causing the code to crash in rare cases, which we are gradually working through and fixing.

The C-grid effort has been led by ECCC with assistance from DMI, NOAA, NRL, NCAR and LANL.

Redesign or update Icepack interfaces to account for needs of DOE's E3SM
We continue to implement the Icepack interface design as new code comes in. In the last year, optional arguments in public Icepack interfaces were refactored in Icepack to conform to the newer design and improve robustness. This change did not affect use of the public Icepack interfaces. Implementation of Icepack in E3SM has required only small changes to Icepack, a sign that the new interface is well-designed.

Merge Icepack with E3SM column physics
The column physics code in E3SM and Icepack have diverged substantially over the past 6-7 years. With assistance from the Consortium, E3SM sea ice modelers have merged changes from MPAS-SI into Icepack, streamlined Icepack by deprecating older code, and updated interface changes to simplify Icepack installation in other drivers such as MPAS-SI. The final merge of Icepack back into MPAS-SI is nearly complete. Several bugs have been found and fixed in both codes, and the Consortium's Quality

Control testing has been ported for use with MPAS-SI's infrastructure, enabling quicker testing of non-bit-for-bit changes and greater confidence in both codes.

Residual ice

NOAA/NWS highlighted a residual ice issue in its testing, in which large expanses of very low ice concentrations remain. This ice most likely does not matter much for simulations but can be problematic for users, e.g. forecasting probable ice thickness for ships. In climate models these low concentrations have simply been ignored, and operational models can simply eliminate this ice when conservation is not required. The problem is likely a mismatch in limiting parameters used for numerical stability, where thermodynamics uses a thickness based parameter and dynamics uses a mass based parameter, leaving a range of very small volumes with no way to remove them. Physics-based and numerical solutions are being explored.

Increase code coverage of test suites

The fraction of CICE code covered by our tests is 76.33% for CICE and 76.85% for Icepack. Most of our coverage testing is done by running realistic configurations (e.g. gx3) with various physical or infrastructure setups, which verify that the code produces reasonable (not necessarily correct) results. We continue to evaluate and improve our testing coverage and infrastructure.

Improve model performance

Several features were refactored to improve performance, driven largely by performance needs for the new VP solver. A second major focus was threading in CICE, which is also nearly complete The 1D EVP solver will be done as part of its new implementation.

Improve build system

The scripts that configure and build the working directories and executable code are robust and stable, although we continue to find ways to improve them in relatively small ways. For instance, we added a check for unwanted tabs in the source code to the automated build system.

Improve automation of testing, documentation

The testing infrastructure continues to perform well with new tests, new test suites, and new unit tests relatively easy to add. Our automated documentation system leverages readthedocs, which underwent several upgrades over the year that required attention from the Consortium to maintain the tool.

Code and documentation maintenance

This is an ongoing task, which includes necessary changes to CICE associated with changes to Icepack; fixes to errors in documentation, machine and build scripts; and broader testing, e.g. we increased namelist flexibility to reduce code aborts when reading them out of order, updated NUOPC drivers for modeling centers' configurations, and continued to maintain the documentation with corrections, clarifications, and updates to the readthedocs environment.

Institute unit tests where it makes sense

Unit testing capability continues to improve as noted above. In particular, the global sum and halo update unit tests were added or expanded with complementary improvements to their performance and robustness. A unit test for EVP on the B grid has been created and is being tested. We plan to develop unit tests for other features, to be implemented as time allows.

Floe size distribution
Work on the floe size distribution continues: test runs in CESM using active waves are causing the floe sizes to become very small; fixing this problem is a science project. As individual issues are found and fixed, they are being incorporated into the Consortium's main repositories.

Restart flexibility
CICE's restart capability writes at a regular (user-specified) interval throughout the simulation. ECCC and NRL have developed in-house capabilities for their prediction systems, which allow restart files to be written only when needed (e.g. after 12 hours and at the very end of the prediction simulation). Other groups could also take advantage of this flexibility. With so much interest, this capability is being brought into the main CICE repository, coded based on general requirements.

Postponed activities
Several tasks have been postponed while projects at various institutions proceed; what the Consortium accomplishes is highly dependent on development and implementation of research programs at the participating institutions, which the Consortium itself doesn't control. However, we check in regularly on progress and will work with them when new code capabilities are ready for testing and inclusion in the Consortium's repos. Examples include the satellite emulator, the variational ridging scheme, and wave-sea ice interactions, all of which are now being worked on through DOE programs, the Mohr-Coulomb rheology from ECCC, and creating kernels for EAP from DMI.

Community Support

Our first workshop and tutorial were held in early 2020, just prior to the pandemic lockdown. The NSF funding left over from the 2020 event needed to be used before the end of September 2022, supporting US-based early-career researcher travel to benefit the Consortium. Melinda Webster, University of Washington and David Clemens-Sewall, University of New Hampshire, visited NCAR in September of 2022 to work on the MOSAiC modeling effort.

DOE program managers Xujing Davis and Sally McFarlane requested that the Consortium contribute to the U.S. Interagency Arctic Research Policy Committee (IARPC) Collaborations biennial planning document for its 2022-2026 Research Plan. One of their objectives is to "Increase coordination and engagement between federal activities and international and non-federal partners who are conducting monitoring, observing, modeling and prediction of the Arctic". The Consortium offered to coordinate and report on three activities:

1. a community workshop to discuss sea ice modeling needs and priorities across the research and operational modeling communities
2. implementation of a new C-grid modeling capability for CICE, needed by multiple modeling centers for effective ice-ocean coupling with their C-grid ocean models
3. creation of a test suite using MOSAiC and other observational data to drive the Icepack sea ice column physics model in Lagrangian studies.

We are working toward all three of these goals, as described in the Plans section below. (2) is a terrific example of interagency and international collaboration to accomplish a common goal. In addition to CICE users, SI3 developers also want a C-grid remapping advection scheme, which could be a good topic for increased collaboration with some European modeling centers.

Elizabeth solicited opinions from Consortium members and the community regarding the greatest needs for sea ice modeling in the next several years. The answer depends on the application, of course, but these ideas were offered (not in order of priority):

- biogeochemistry
- understanding sea ice predictability and improving skill for seasonal forecasting
- improving coupled atmosphere and ocean models
- seamless incorporation of observations (e.g. via simulators or emulators)
- near-coastal physics, e.g. icebergs, landfast ice, and sea ice's buttressing effect for ice shelves
- sea ice ridging and morphology
- computational efficiency, including scalability and use of GPUs

Elizabeth also held one-on-one discussions with each of the EOB members. A summary of highlights and suggestions from these discussions:

- Feedback on Consortium effectiveness was quite positive
- Comments regarding Consortium technical work
  - Consider modeling and software architecture strategies for flexible coupling
  - Coordinate a data assimilation discussion
  - Optimize code performance
  - Be ready to take advantage of technological advances in hardware, software, programming models, etc.
  - IOPAN users are running CICE at ½ n.m. resolution in the Baltic Sea, apparently without issues
- Suggestions regarding community
  - Entrain next-generation participants
  - Provide an online tutorial / classroom teaching tool
  - Entrain more European participation / collaboration with SI3
  - Reach out to users of older versions of the model, e.g. ROMS, NASA/GMAO, NorESM
- Comments regarding the EOB
  - the EOB's primary function is to step in, in case we need help
  - socialize major future plans with the EOB
  - continue without a chair for now
  - members could be more effective if they have more sea ice modeling background

General information	https://github.com/CICE-Consortium/About-Us
How to contribute	https://github.com/CICE-Consortium/About-Us/wiki/Contributing
General information wiki	https://github.com/CICE-Consortium/About-Us/wiki
Resource index	https://github.com/CICE-Consortium/About-Us/wiki/Resource-Index
Icepack wiki	https://github.com/CICE-Consortium/Icepack/wiki
Icepack documentation, user guide	https://readthedocs.org/projects/cice-consortium-icepack/
CICE wiki	https://github.com/CICE-Consortium/CICE/wiki

CICE documentation, user guide	https://readthedocs.org/projects/cice-consortium-cice/
Zenodo Community (DOIs)	https://zenodo.org/communities/cice-consortium
2020 Workshop and Tutorial	http://www.cesm.ucar.edu/events/2020/cice-icepack/ http://www.cesm.ucar.edu/events/2020/cice-icepack/coursework.html

Visibility

There are 119 CICE forks of the main repository and 100 Icepack forks. Since its inception on December 27, 2018, our user forum has received 461 messages in 93 different threads.

The Consortium hosted two talks during our regular meetings, which were more broadly advertised.

- Robert Osinski (IOPAN) presented his sensitivity study of CICE parameters and dynamics configurations using the RASM model at very high resolution (1/12 and 1/48 degree, 20-minute coupling timesteps) in both ice-ocean and fully-coupled configurations. In addition to testing the elastic-viscous-plastic (EVP) and elastic-anisotropic-plastic (EAP) dynamics options, he also chose a range of values for some parameters that affect the ice's interactions with the atmosphere and ocean models.
- Till Rasmussen (DMI) presented the 1D EVP solver, for which he and others at DMI and Intel refactored the EVP code to reduce memory and increase performance. They implemented four different OpenMP approaches and tested them on 4 different Intel hardware architectures, including one with GPUs. A manuscript describing the results is in preparation.

Publications

Dupont, F., D. Dumont, J.-F. Lemieux, E. Dumas-Lefebvre and A. Caya, A probabilistic seabed-ice keel interaction model, The Cryosphere, 16, 10.5194/tc-16-1963-2022, 2022

Holland, M., and E. Hunke, Arctic Sea Ice in Large-Scale Earth System Models, Oceanography 35, https://doi.org/10.5670/oceanog.2022.113, 2022.

Lee, Y. J., Maslowski, W., Cassano, J. J., Clement Kinney, J., Craig, A. P., Kamal, S., Osinski, R., Seefeldt, M. W., Stroeve, J., and Wang, H.: Causes and evolution of winter polynyas north of Greenland, The Cryosphere, 17, 233-253, 10.5194/tc-17-233-2023, 2023.

Ponsoni Leandro, Ribergaard Mads Hvid, Nielsen-Englyst Pia, Wulf Tore, Buus-Hinkler Jørgen, Kreiner Matilde Brandt, Rasmussen Till Andreas Soya. Greenlandic sea ice products with a focus on an updated operational forecast system. Frontiers in Marine Science. 2023. https://www.frontiersin.org/articles/10.3389/fmars.2023.979782; DOI=10.3389/fmars.2023.979782

Sandven, S., Spreen, G., Heygster, G. *et al.* Sea Ice Remote Sensing—Recent Developments in Methods and Climate Data Sets. *Surv Geophys* (2023). https://doi.org/10.1007/s10712-023-09781-0

Presentations

Allard, Richard., G. Panteleev, D. Hebert, E. Douglass, J. Dykes. Development of spatially-varying grounding coefficients for landfast ice in CICE6, AGU Ocean Sciences Meeting, February 2022

Allard, Richard. NAVY ESPC Sea Ice Assimilation: Present Capabilities and Planned Enhancements, 11th International Ice Charting Working Group Data Assimilation Workshop, Oslo, Norway, March 22, 2023 (poster).

Allard, Richard. Development and testing of spatially varying landfast ice parameters in CICE6, International Glaciology Society Symposium on Sea Ice Session: Arctic and Antarctic landfast sea ice, Bremerhaven, Germany June 4-9, 2023.

Bailey, David. Sea Ice: Model Developments, Predictability and Prediction. UFS All Hands Meeting (Virtual) June 30, 2023.

Hunke, Elizabeth. CICE Consortium: Advancing sea ice modeling. American Geophysical Union Fall Meeting session "SY008 - Community Modeling and Open Innovation to Advance Earth Prediction Systems", December 2022

Hunke, Elizabeth. Briefing for DOE Arctic Energy Office, March 3, 2022

Hunke, Elizabeth. Briefing for Interagency Arctic Research Policy Committee session on "Achievements of the 2017-2021 Arctic Research Plan: Accomplishments in Modeling" March 7, 2022 https://zenodo.org/record/6335509

Hunke, Elizabeth. Modeling sea-ice for climate research and short-term forecasting, Mathematics of Sea Ice Workshop, Isaac Newton Institute, Cambridge UK, September 20, 2022

Hunke, Elizabeth. Modeling ice and polar oceans – Highlights from the CICE Consortium and LANL, Consortium for Ocean and Sea Ice Modeling in Australia, online, November 3, 2022

Hunke, Elizabeth. CICE6 – Highlights from the CICE Consortium, Bluelink Science Meeting, Australia, online, March 9, 2023

Hunke, Elizabeth. CICE Consortium Progress and Plans E3SM All-Hands Meeting, June 27, 2023 (poster)

Rasmussen, Till. Progress of the Arctic sea ice forecast at the Danish Meteorological Institute, 11th International Ice Charting Working Group Data Assimilation Workshop, Oslo, Norway, March 22, 2023, Link: TillRasmussen3.pdf

Rasmussen, Till, Poulsen, J. W., Ribergaard, M. H., Rethmeier, S., Hunke, E. C., and Craig, A. P.: Refactorization of the EVP solver, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-15209, https://doi.org/10.5194/egusphere-egu23-15209, 2023. (oral)

Ribergaard, M. H., Rasmussen, T. A. S., Ponsoni, L., Kreiner, M. B., Buus-Hinkler, J., Hansen, T. W., and Nielsen-Englyst, P.: Sea ice information for the Greenlandic community, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-16314, https://doi.org/10.5194/egusphere-egu23-16314, 2023. (poster)

Forum	https://bb.cgd.ucar.edu/cesm/forums/cice-consortium.146/
Zenodo community	https://zenodo.org/communities/cice-consortium
Github government community	https://government.github.com/community/#research

Plans

The Consortium is planning a hybrid user workshop for 2024, in support of the IARPC Arctic Research Plan for 2022–2026. Several Consortium modeling centers (NOAA, NCAR, ECCC, NRL, LANL) are working to include wave-ice interactions in their systems, and we decided to focus our upcoming workshop on this topic and data-model integration. NSF has agreed to fund travel for ~10 early-career researchers, and LANL will provide administrative assistance and funding for the venue. The workshop is currently planned for May or June 2024, due to long lead times needed for LANL administrative support and a venue in Santa Fe. We are planning a hands-on workshop project as a tutorial, with a goal of training next-generation researchers. One challenge for a standard tutorial is setting up a common computing environment and securing the computing resources, either in the cloud or on HPC somewhere. We plan to leverage a containerized version of CICE that already exists using Docker software.

While we do not want to encourage the model (Icepack or CICE) to be run in stand-alone mode, Icepack itself is quite popular for Lagrangian studies, and the Consortium plans to coordinate MOSAiC data for use in Icepack, similar to the current SHEBA forcing data set but including more data (e.g. biogeochemistry). An NCAR postdoc is implementing a capability to run Icepack with MOSAiC data under an NSF-funded project.

The CICE user community including Consortium members expect to benefit by having a C-grid sea ice dynamical core, which is mostly complete. We will continue to validate this new C-grid code, fixing issues as they arise. We plan to write a peer-reviewed paper to document the C-grid discretization of the momentum and stress equations and the changes needed for the advection code, demonstrate the checkerboard issue and how it is solved, and show simulation comparisons in 'realistic' configurations.

Other plans include developing boundary conditions for regional CICE configurations, spatially varying parameters for the landfast ice parameterization, and a new grounding scheme. Plans for the 1D EVP project include adding unit tests, pulling the dynamics calculation off onto separate hardware running concurrently with the rest of the sea ice model, and extending the 1D EVP ideas to other parts of the code.

The Consortium's task list is constantly changing as tasks are completed and new ones arise, many to address issues submitted by external community members. Ongoing, longer term tasks include continuing to automate the test suites and documentation, deciding if and how data assimilation capabilities that have been developed could be included in the Consortium's repositories, and incorporating other community enhancements as they become available. Another set of longer term tasks of interest to all of our Consortium member institutions and the broader community involves enhancing our metrics and analysis capabilities. The Consortium can assist in coordinating community efforts, e.g. the NSF MOSAiC project mentioned above and NOAA's establishment of formal metrics for UFS, which is being led by EMC and NCAR under NOAA support.

Most Consortium activities involve team members from multiple institutions, overseen by the institution responsible for the relevant Consortium Team but often led by people at other institutions. Ongoing and future work in the table below includes some items mentioned above.

Table of Plans

Team	New and ongoing effort	Lead	Future work	Lead
Testing and Analysis	Include metrics and scripts for verification against MOSAiC and other observations	LANL NOAA NASA	Begin development of a CICE Consortium diagnostics package	NRL NOAA
	Increase code coverage of test suites	NOAA IOPAN	Implement MOM6 test domains/cases for CICE	NCAR
	Institute unit tests where it makes sense	NOAA	Create test options with major centers' namelist configurations.	NRL
			Incorporate the satellite emulator developed by Navy/DOE	LANL
CICE dynamical core	Add Mohr-Coulomb rheology	ECCC	Create kernels for EAP similar to EVP	DMI
	Refactor EVP dynamics code	DMI	Refactor the dynamics code to have unique drivers	DMI ECCC
	Validate C-grid option	ECCC	Integrate C-grid into ECCC systems	ECCC
	Integrate C-grid into NOAA UFS, support C-grid coupling development	NOAA	Integrate C-grid into Navy ESPC and COAMPS systems.	NRL
Icepack	Port Icepack developments from E3SM and elsewhere	LANL	Add variational ridging scheme and interactions with the ice thickness and floe size distributions	LANL
	Create MOSAiC forcing, benchmarking and evaluation dataset for Icepack	LANL NCAR NASA	Improve radiation scheme using MOSAiC measurements	LANL NCAR

	Remove residual ice	LANL DMI	Fully implement conservation budgets	NCAR
Infrastructure	Refine Icepack interfaces and improve Icepack robustness and usability	NOAA	Develop boundary conditions for regional CICE configurations	DMI ECCC
	Debug and optimize threading	DMI NOAA		
Community Support	Improve online documentation	NCAR NASA	Document/publish coupling considerations, including thickness biases	LANL
	Improve processes for documenting how well new features have been tested and documented	NCAR NASA	Update tutorial for online learning	NCAR NASA
	Plan and hold a user workshop	LANL NCAR NASA		
General	Address issues and user questions as needed			All
	CICE: https://github.com/CICE-Consortium/CICE/issues			
	Icepack: https://github.com/CICE-Consortium/Icepack/issues			

Challenges

The biggest technical challenges for the CICE and Icepack codes and repositories are

- maintaining Icepack as a separate model from CICE
- making it as easy as possible for users to keep their local versions up to date with the Consortium's repositories
- new feature testing and documentation
- direct coupling of CICE with ocean models (e.g. MPI routines are not the same and not optimized)

Software maintenance continues to be a challenge for the Consortium, particularly due to the large amount of redundancy between the CICE and Icepack drivers. The question that comes up is how much additional infrastructure to add to Icepack, as a standalone model (history, forcing, etc), as opposed to running CICE in a column-physics-only mode. Using CICE as the driver for Icepack would require simplifying the CICE driver for a column configuration and encouraging Icepack users to only work with CICE, rather than using the Icepack driver. Another option could be to move the shared infrastructure into a separate repository. To ameliorate modeling centers' concerns with the amount and complexity of code from our repositories that must be linked with their code bases, the CICE and Icepack repositories could be refactored so that some unwanted code (e.g. drivers unnecessary in coupled modeling centers' codes) would not have to be downloaded, while other code (e.g. the time manager) could be shared. For example, the column physics code in Icepack could itself be a separate submodule. This major change would save having to implement changes in both CICE and Icepack drivers, but would impact users who already use Icepack as a Lagrangian type of model. This discussion is ongoing.

Some code users are posting releases from their forks on the Consortium's zenodo community page, to satisfy journal requirements for providing code used in their publications. An ongoing topic of discussion is whether and how to better coordinate these contributions, integrating them into the Consortium's main repositories and/or correcting the metadata on zenodo, which the Consortium does not own and therefore can not change. We are working with individual contributors to either retract/reject the entries or fix their metadata.

Although all new features currently must be documented in the User and Science Guides, we need additional documentation of how the new code was tested (which tests, compilers, architectures), what the results were, and some indication of aspects that weren't sufficiently tested (which must be defined). The extent of testing needed is somewhat case dependent, and we do not want to intimidate code contributors with excessive requirements. The Consortium provides developers with guidance for testing their modifications, when we are alerted to those changes in advance, or in response to pull requests.

Direct coupling with ocean models is outside the scope of the Consortium's activities, but we try to connect users with each other whenever possible, to increase knowledge sharing. Maintaining the coupling caps also continues to be a challenge. The Consortium can not test these because the infrastructure needed is unique to each modeling center, and so we rely on the modeling centers to maintain the caps. Fortunately, now CESM and NOAA UFS are using the same cap.

Major agency contributions since February 2022

Agency/ Institution	**Sponsor, EOB Member**	**Team members**	**Contributions**
DOE/LANL	Xujing Davis, Renu Joseph Dave Bader	Elizabeth Hunke Andrew Roberts Nicole Jeffery Erin Thomas	Project leadership and reporting (prioritization, planning, and oversight); Icepack updates esp. the merge into E3SM; visibility, code releases, Zenodo curation
NSF/NCAR	Eric DeWeaver, Jean-Francois Lamarque (former), Marika Holland (acting)	David Bailey Alice DuVivier	Community liaison, workshop planning, forum oversight and response, documentation; C-grid implementation, salinity coupling options, improved history and restart output

DoD/NRL	Dan Eleuterio, Scott Harper, Rick Allard (acting)	Rick Allard David Hebert	Test design/ implementation, JRA55-do forcing data; C-grid testing
NOAA/OAR/WPO	Arun Chawla	Tony Craig (contractor funded by NOAA exclusively for general CICE support as software engineer and code manager)	Software engineering (SE), esp. Icepack interface, coupling infrastructure; run/build scripts, I/O; scheduled/extended testing, automation, code coverage, unit tests; C-grid infrastructure; leads all code releases
NOAA/NWS	Hendrik Tolman	Bob Grumbine	Testing in NOAA's coupled systems
NASA	Thorsten Markus, Nathan Kurtz	Alek Petty	Workshop planning, tutorial material development
ECCC	Fraser Davidson	JF Lemieux Philippe Blain Frederic Dupont	C-grid effort leadership and technical work; improvements to implicit VP solver; SE support including improved run/build scripts; documentation
DMI	Jacob L. Høyer	Till Rasmussen Mads Ribergaard	EVP kernel, refactorization, dynamics testing; C-grid development
IOPAN	Slawomir Sagan	Robert Osinski	Testing in RASM for both forced and fully coupled configurations

Trackable Consortium Output

Products	**Identifiers**
Through June 2018	
CICE repository	http://doi.org/10.5281/zenodo.1205674
CICE v6.0.0.alpha release	http://doi.org/10.5281/zenodo.1205675
Icepack repository	http://doi.org/10.5281/zenodo.1213462
Icepack v1.0.0 release	http://doi.org/10.5281/zenodo.1215746
Icepack v1.0.2 release	http://doi.org/10.5281/zenodo.1213463
Roberts et al., *Phil. Trans. Royal Soc. A,* 2018	http://doi.org/10.1098/rsta.2017.0344
Allard et al., EGU Abstract	Geophysical Research Abstracts Vol. 20, EGU2018-9495, 2018
Through December 2019	
CICE v6.0.0 release	http://doi.org/10.5281/zenodo.1893041
CICE v6.0.1 release	http://doi.org/10.5281/zenodo.3351684
CICE v6.0.2 release	http://doi.org/10.5281/zenodo.3516944
CICE v6.1.0 release	http://doi.org/10.5281/zenodo.3568214
Icepack v1.1.0 release	http://doi.org/10.5281/zenodo.1890602
Icepack v1.1.1 release	http://doi.org/10.5281/zenodo.3251032
Icepack v1.1.2 release	http://doi.org/10.5281/zenodo.3516931
Icepack v1.2.0 release	http://doi.org/10.5281/zenodo.3568288
Through February 2021	
CICE v6.1.1 release	https://doi.org/10.5281/zenodo.3712304
CICE v6.1.2 release	https://doi.org/10.5281/zenodo.3888653
CICE v6.1.3 release	https://doi.org/10.5281/zenodo.4004992
CICE v6.1.4 release	https://doi.org/10.5281/zenodo.4359860
Icepack v1.2.1 release	https://doi.org/10.5281/zenodo.3712299
Icepack v1.2.2 release	https://doi.org/10.5281/zenodo.3888633
Icepack v1.2.3 release	https://doi.org/10.5281/zenodo.4004982

Icepack v1.2.4 release	https://doi.org/10.5281/zenodo.4358418
Blockley et al., *BAMS, 2020*	https://doi.org/10.1175/BAMS-D-20-0073.1
Hunke et al., *Curr. Clim. Change Rep.*, 2020	https://doi.org/10.1007/s40641-020-00162-y
Hunke, *SIAM News,* 2020	https://sinews.siam.org/Details-Page/the-challenges-and-opportunities-of-one-size-fits-all-sea-ice-models
Through February 2022	
CICE v6.2.0 release	https://doi.org/10.5281/zenodo.4671172
CICE v6.3.0 release	https://doi.org/10.5281/zenodo.5423913
CICE v6.3.1 release	https://doi.org/10.5281/zenodo.6314188
Icepack v1.2.5 release	https://doi.org/10.5281/zenodo.4671132
Icepack v1.3.0 release	https://doi.org/10.5281/zenodo.5423061
Icepack v1.3.1 release	https://doi.org/10.5281/zenodo.6314133
Bouchat et al., *JGR Oceans*, 2022	https://doi.org/10.1029/2021JC017667
Hutter et al., *JGR Oceans*, 2022	https://doi.org/10.1029/2021JC017666
Mehlmann et al., *JAMES*, 2021	http://dx.doi.org/10.1029/2021MS002523
Zampieri et al., *JAMES*, 2021	https://doi.org/10.1029/2020MS002438
Through June 2023	
CICE v6.3.2 release	https://doi.org/10.5281/zenodo.6967695
CICE v6.3.3 release	https://doi.org/10.5281/zenodo.7419531
Icepack v1.3.2 release	https://doi.org/10.5281/zenodo.6967671
Icepack v1.3.3 release	https://doi.org/10.5281/zenodo.7419438
Dupont et al, The Cryosphere, 2022	https://doi.org/10.5194/tc-16-1963-2022
Holland and Hunke, Oceanography, 2022	https://doi.org/10.5670/oceanog.2022.113
Ponsoni et al., Frontiers in Mar. Sci., 2023	https://www.frontiersin.org/articles/10.3389/fmars.2023.979782; DOI=10.3389/fmars.2023.979782
Sandven, et al., Surv Geophys, 2023	https://doi.org/10.1007/s10712-023-09781-0
Briefing for Interagency Arctic Research Policy Committee, March 7, 2022	https://zenodo.org/record/6335509

EGU poster, April 2023	https://doi.org/10.5194/egusphere-egu23-16314
EGU oral presentation, April 2023	https://doi.org/10.5194/egusphere-egu23-15209